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Research Note

V 701 Scorpii and Its Place among Early Contact Binaries

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Summary. A solution of light curves of the early type eclipsing binary V 701 Scorpii shows a large degree of overcontact, with the surface of the common envelope lying about halfway between the inner and outer contact surfaces. This result is independent of the assumed mass ratio, q, for which no spectroscopic value is known. The mass ratio is determined only very weakly from the photometry, due to the low inclination. We have assumed $q=1.00$, partly because the photometric solution fits the observations slightly better for this value than for, say, $q=0.6$, but mostly because the large degree of overcontact should lead to an extremely large mass flow (and period change) if the masses are unequal. If q is, in fact, unity, V 701 Sco is the only contact binary presently known which escapes the Kuiper (1941) paradox by reason of having equal mass components. It now appears that contact binaries are rather common among early-type stars, as the contact natures of SV Cen, BH Cen, V 1010 Oph, V 382 Cyg, 29 C Ma, V 729 Cyg, V 1073 Cyg, AU Pup, V 535 Ara and RZ Pyx, in addition to V 701 Sco, have been established within the last two years. V 701 Sco is on or close to the zero age main sequence and therefore may have been formed by fission essentially in its present state. For further progress in understanding this binary there is an acute need for radial velocity and time of minimum observations.

Key words: contact binaries — stellar evolution

Introduction

Recently one of us (Leung, 1974) obtained blue and visual light curves of the southern eclipsing binary V 701 Sco but did not publish a rectifiable model type solution for photometric elements because of the low orbital inclination. With a low inclination, the eclipses are too shallow after rectification to provide much information through the rectifiable model approach, which finds a solution entirely from the depths and shapes of the eclipses. Furthermore, as we shall see below, V 701 Sco is a contact binary, for which several of the rectification approximations are at their weakest. One expects, however, that the situation should be much improved under analysis by the more recent models and solution techniques, which extract information not only from the eclipses but also from the proximity effects. Here we discuss our application of the Wilson-Devinney (1971) model and differential corrections process to the Leung observations. The results show that V 701 Sco is an early-type contact system with a rather large degree of overcontact. Here, *early type* means earlier than the hottest WUMa stars, and thus in a range of spectral type in which the common envelope should be radiative rather than convective. Since the system seems to be unevolved or only slightly evolved, it provides an interesting test of the idea that zero-age contact binaries can exist only in certain specific exceptions to an argument which otherwise forbids their existence (Kuiper, 1941). For V 701 Sco, a likely exception appears to be the special case of equal mass components.

The apparent magnitude at maximum brightness and period are $V_{MAX}\simeq 8^{m}.1$, $P=0^{d}.762$. Popper (1966) estimated the spectral type to be about B 5 (presumably on the MK system), but the observed color (Eggen, 1967) indicates a type no later than about B 3.

It is only within the past year or two that the existence of early-type contact binaries has been clearly demonstrated. That is, the early-type systems called contact binaries were previously known to have component dimensions of the right order to be in contact, but near-contact was also a possibility. It now seems that true contact systems occur rather commonly among the early-type stars. Examples in addition to V 701 Sco include SV Cen (Rucinski, 1976; Wilson and Starr, 1976); BH Cen (Leung and Schneider, 1977); RZ Pyx and V 382 Cyg (Devinney, 1974); V 1010 Oph (Leung and

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Table 1. Fixed and auxiliary parameters[a]

M 2/M 1	1.00	r_1/a (polar)	0.393 ± 0.001 p.e.
$T1$ (polar)	20500 K	r_1/a (side)	0.420 ± 0.001
x (λ 5500)	0.40	r_1/a (back)	0.479 ± 0.002
x (λ 4400)	0.45	r_1/a (mean)	0.426 ± 0.001
Ω inner contact	3.7500		
Ω outer contact	3.2068		
$\frac{(\Omega\ ic - \Omega)}{(\Omega\ ic - \Omega\ oc)}$	0.51 (percent overcontact)		

[a] Radii for the secondary component are necessarily the same as those of the primary, since $q = 1.00$. The probable errors of the relative radii were found by multiplying the probable errors in Ω (Table 2) by $dr/d\Omega$, which can be found by differentiating Equation (1) of Wilson and Devinney (1971)

Wilson, 1977); 29 C Ma, V 729 Cyg, V 1073 Cyg, AU Pup, V 535 Ara and perhaps AO Cas (Leung, 1977)[1].

The scanty observational history of V 701 Sco was summarized by Leung (1974). The binary is a member of the cluster NGC 6383. According to Popper (1966) the system is a very difficult one for radial velocities, but velocity curves would be very valuable if these difficulties could be overcome.

II. System Parameters

In Tables 1 and 2 we list the fixed and adjusted parameter values from our differential corrections solutions, for which the observational input consisted of normal points of from 2 to 13 observations each, formed from the Leung (1974) photometry. The blue and visual light curves were fitted simultaneously and the resulting theoretical light curves are compared with the observations in Figure 1. The solution was done in a contact mode [Mode 3, as described in Leung and Wilson (1977)], with $T2$ (secondary temperature) treated as a free parameter. The parameters i (inclination), $T2$, Ω (Roche "modified potential"), and the relative monochromatic luminosities, L_1 (λ 5500) and L_2 (λ 4400), were adjusted. According to Eggen (1967), $B-V$ and E_y for V 701 Sco are $+0^m.07$ and $0^m.31$, respectively, so that $(B-V)_0$ should be -0.24. Recent photometry by Eggen (1976) gives the Strömgren color index $b-y$ as $+0^m.055$ which, according to Strömgren's (1963) calibration, would mean a $B-V$ of $+0.10$, and thus a $(B-V)_0$ of $-0^m.21$. We adopt a value for $(B-V)_0$ intermediate between these, but closer to that measured directly on the B, V system, of $-0^m.23$. The Morton-Adams (1968) temperature calibration then gives a (mean disk) temperature of 19500 °K. Because of gravity darkening the polar temperature would be somewhat higher, and we have estimated $T1$ (polar) to be 20500 °K, based on trial calculations of surface temperature distribution. The limb darkening coefficients were estimated from linear fits to tables by Carbon and Gingerich (1969).

If one accepts the internal probable errors (Table 2) as reasonably realistic, an interesting and apparently well-founded result appears in the solution, despite the low inclination and resultant shallow eclipses. This is that the degree of overcontact is quite large (0.51, where this number represents the fractional distance of the actual surface of the common envelope from the inner to the outer contact surfaces, measured in terms of potential energy). Unfortunately, the low inclination makes it virtually impossible to obtain a unique value for the mass ratio from the light curves, and we found that an excellent fit to the observations was possible for several mass ratios in the range of 0.5 to unity. Actually the fit was slightly better for q values near unity, but convergence toward this value from other q values was extremely slow. However for all these solutions, with their quite different mass ratios, the degree of overcontact is about the same—halfway between inner and outer contact. Incidentally, the derived inclination also appears to be independent of the assumed mass ratio, always being within one degree of the value given in Table 2.

According to Kuiper's (1941) argument, zero-age stars with radiative envelopes should exist in contact and in equilibrium only for equal masses. Since the degree of contact here is very large, and since there is no positive evidence at present for large-scale mass exchange in the system (which allows an equilibrium configuration), we have assumed $q = 1.00$ for our solution. This solution (Table 2) now appears preferable to preliminary ones we published in abstracts (Leung and Wilson, 1974, 1976), for which q was about 0.6, both in terms of astrophysical reasonableness and slightly better agreement with the observations.

III. Evolutionary State

Three of the four readily conceivable exceptions to Kuiper's (1941) argument against the existence of contact binaries have now been identified or perhaps identified among observed binaries[2]. These exceptions are:

1. Convective envelope exception: As pointed out by Lucy (1968), all of the WUMa-type binaries probably fall in this category. Kuiper's argument applies directly only for radiative cases.

2. Non-equilibrium exception: Clearly, SV Centauri (Rucinski, 1976; Wilson and Starr, 1976) must be an

[1] Just prior to submission of this paper, a theory for constructing equilibrium models of both early and late contact binaries appeared (Shu et al., 1976). Their theory avoids the Kuiper paradox without having to invoke exceptions for particular cases, in contrast with our paper, which discusses the observational situation within the context of the Kuiper paradox, and thus focusses attention on the possible exceptions. (Case 2 of our Section III lies outside the scope of their theory.) Obviously the newfound abundance of early-type contact systems will provide a basis for deciding whether the Kuiper paradox is of continuing or only historical interest

[2] Briefly, the argument states that the mass-radius relations for the two stellar components and for a Roche Model configuration must be the same, for equilibrium contact to be possible, and that such is normally not the case

Table 2. Adjusted parameters

i	$66.76 \pm 0.^{\circ}14$ p.e.	$L_1/(L_1+L_2)$ [λ 5500]	0.4981 ± 0.0014 p.e.
$T2$ (polar)	$20586\,K \pm 59\,K$	$L_1/(L_1+L_2)$ [λ 4400]	0.4978 ± 0.0016
Ω	3.471 ± 0.005		

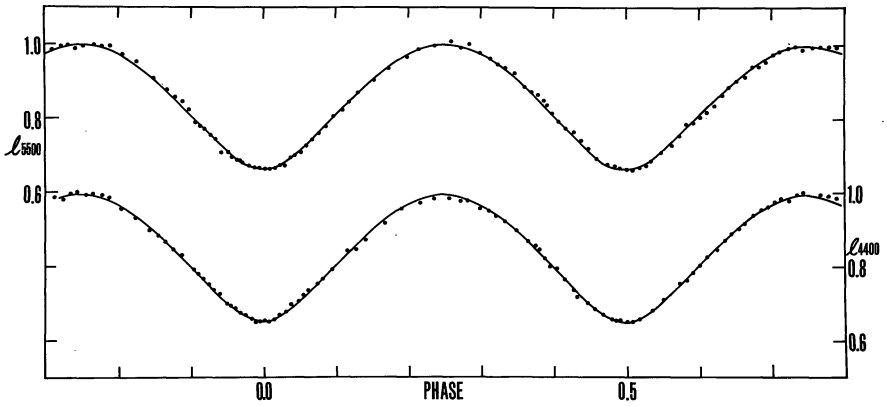

Fig. 1. Comparison of the theoretical and observed light curves. The λ 5500 Å light curve is above, λ 4400 below

example because the system is well over-contact and has the enormous mass transfer rate of about $4\,10^{-4}\,M_{\odot}$/yr, as deduced from the period change.

3. Equal mass exception: We suspect that V 701 Sco fits this description, although we have not proved it because our photometric solutions are only slightly better for $q=1.0$ than for, say, $q=0.6$. Another suspect is BH Cen (Leung and Schneider, 1977). Again, we emphasize the importance of radial velocity work on this system.

4. Evolved star exception: If a system has passed through an interval of mass exchange which reversed the mass ratio, it could possibly find temporary equilibrium or near-equilibrium in which the Roche mass-radius relation is satisfied by the components. Perhaps some of the cases cited in Section I will be found to belong to this category, although little can be said at this moment on that possibility.

The most important kind of information presently needed to distinguish among categories 2, 3 and 4 is period change information, through observations of times of minima. The available data are inadequate, for V 701 Sco and several of the other binaries mentioned above, even to place interesting upper limits on rates of period change. Observed times of minima have been summarized by Leung (1974). The early visual observations are very inaccurate, Leung's photoelectric observations cover a time span of only 11 days, and the two groups of observations taken together amount, in effect, to only two data points. A single photoelectric time of minimum observed now would either establish that the period is changing or place a useful upper limit on dP/dt. However, if q turns out to be accurately equal to unity, there could be large scale mass exchange without an observable period change, since dP/dt is proportional to $(q-1)$ in conservative mass exchange.

In Figure 2 we show the HR diagram location for the components of V 701 Sco, on the assumption of equal masses. The spectral types come from the adopted value of $(B-V)_0$ (cf. discussion in Section II) and the Morton-Adams (1968) calibration, while M_v is that supplied by Eggen (1976), corrected for interstellar extinction and for the binary nature of the system. The components are above, but rather near to the ZAMS. After correction for its binary nature, in fact, V 701 Sco is at the upper edge of the scatter band in Eggen's main sequence for NGC 6383. Furthermore, since some departure from the ZAMS is expected due to the relatively rapid rotation of the system, V 701 Sco could be only negligibly evolved, within observational error. Thus an evolutionary expla-

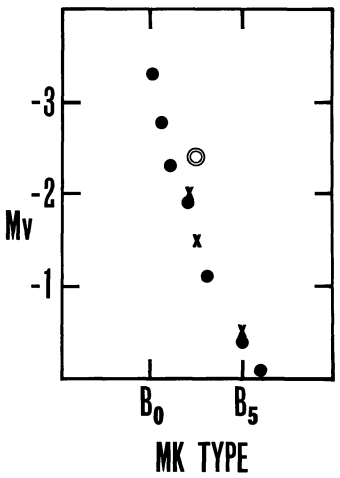

Fig. 2. HR diagram showing the location of the components of V 701 Sco (concentric circles) with respect to the ZAMS. In our solution, the components are virtually identical. Crosses mark the Sandage (1957) ZAMS, while dots mark that of Morton and Adams (1968)

nation for the present configuration (i.e. Roche lobe overflow followed by large-scale mass exchange) seems to us less likely than direct formation of the binary in essentially its present state, presumably by fission.

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